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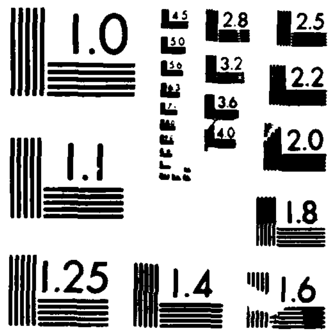

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AIR GAP TESTING USING TRAILING WIRE ANTENNA (TWA) WAVEFORM

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August 1987

Final Report

Approved for public release; distribution unlimited.

AIR FORCE WEAPONS LABORATORY
Air Force Systems Command
Kirtland Air Force Base, NM 87117-6008

This final report was prepared by the Air Force Weapons Laboratory, Kirtland Air Force Base, New Mexico under Job Order 88092605. Lieutenant David W. Metzger (NTA) was the Laboratory Project Officer-in-Charge.

This technical report has been reviewed and is approved for publication.

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Results of tests of various electrode geometries subjected to high voltage electrical discharge are reported along with test conduct. Three geometries (point-plane, rod-plane, and rod-rod) were tested with both positive and negative voltages. The effect of a uniform field on breakdown voltage was also investigated. The data obtained were compared to the standard lightning breakdown data. The data corresponded well (i.e., within 10 percent) with all other data for negative voltages. Thus, the AWRE voltage holdoff formula is a reasonable method for determining negative voltage breakdown.

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INTRODUCTION

The Air Force Weapons Laboratory's Pulse Power Section (AFWL/NTAOP) was tasked with establishing a data base for the upgrading of specific electromagnetic pulse (EMP) simulators. To accomplish this, tests were conducted to determine flashover voltages for various materials. Data are available for the breakdown of air for various geometries and waveshapes, but not for the breakdown of air using the trailing wire antenna (TWA) waveshape (1.7 μs risetime and 37 μs decay time). This report is the outcome of a testing program undertaken to gain air breakdown data for the TWA waveshape.

TESTING PROGRAM

The tests were designed to produce TWA waveshape breakdown data to compare with available data for the lightning waveshape (1.2 μs risetime, 50 μs decay time).

The test parameters were specifically selected to compare results with breakdown data previously measured by Carrara, Kuffel, and Abdullah for a lightning waveshape. The TWA waveshape data are also to be compared with calculated breakdown voltages determined from the British Atomic Weapons Research Establishment (AWRE) high voltage standoff distance formulas (Appendix A).

The Ferranti Impulse Generator (FIG) was configured to produce the recommended waveform for testing TWA. The tests were performed using the three geometries used in the lightning simulation; point-plane, rod-plane, and rod-rod with gaps between 0.5 and 3.5 m for both positive and negative voltages.

The first series of tests used the standard up-down 50 percent breakdown method. However, the breakdown voltage did not vary enough to require using this method.

A-1

Additional tests were made using a negative rod-plane gap with a field shaping electrode included to determine the effect of the uniform field on breakdown. The uniform and nonuniform fields are compared in Fig. 1.

The uniform and nonuniform field tests were done the same way except that uniform tests used the Mobile Upper Electrode (MUE) with the rod-plane geometry (Fig. 2).

RESULTS

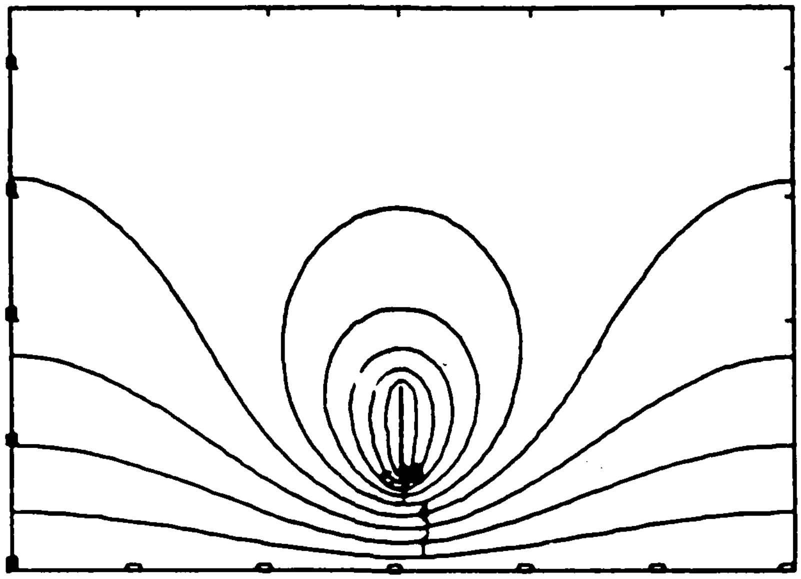
Results of the nonuniform field tests are shown in Table 1. These data are plotted in Fig. 3. Figure 3 shows that the holdoff voltage levels for each different geometry approach some particular value. In the worst negative case (rod-rod), the value is 0.5 MV/m. For the worst positive case (rod-plane), the value is 0.4 MV/m. Figure 3 also shows that the positive holdoff voltages are always lower than the negative holdoff voltages for a given geometry. This is why negative polarity is used in most high voltage designs.

After correcting the negative data to sea level with a factor of 0.83 (Ref: p. 97 BDMMSC/a Task Report 307-RTa-84-001), it was compared to flash-over data obtained by G. Carrara, CIGRE paper no. 328, Appendix II, 1964 (Fig. 4). The FIG data compares closely (i.e., within 10 percent) with the Carrara and AWRE data. See the Appendix, considering the slightly different wave-shapes (TWA versus lightning simulation).

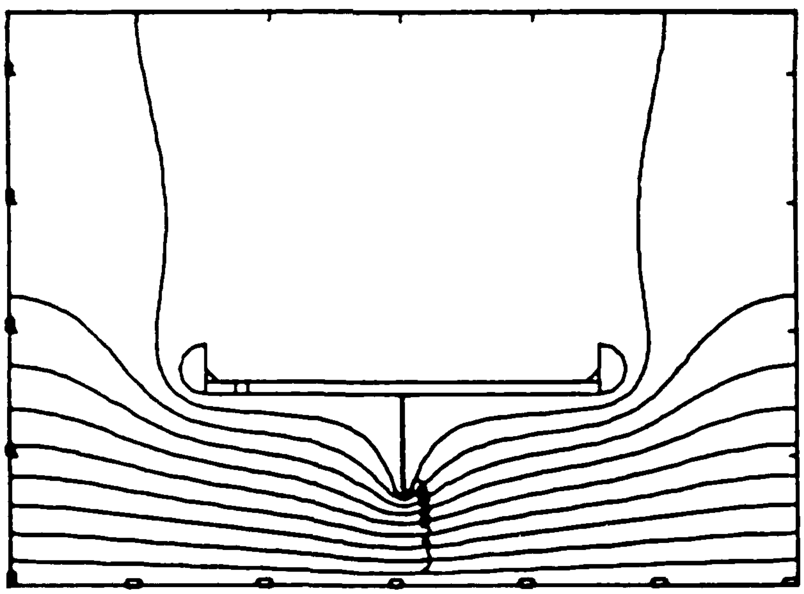
The positive data were compared to the AWRE data in the same way, but did not compare well (Fig. 5).

CONCLUSION

The most effective voltage hold-off is with negative voltages. Unless some special-purpose test is being performed, the normal test system should use a negative voltage.



(a) nonuniform field



(b) uniform field

Figure 1. Comparison of uniform and nonuniform fields.

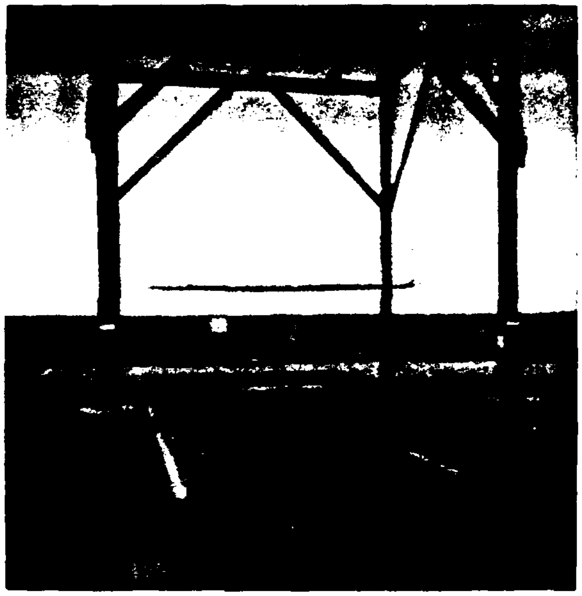


Figure 2. Uniform field test setup.

Table 1. Nonuniform Field Tests Condensed Test Data

The condensed test data for the nonuniform field tests are as follows:

(Note: All data were taken 1 mi above sea level)

Negative Voltage, Point-Plane

spacing (m)	holdoff (MV/m)	Time to Breakdown (s)
0.5	1.0	3 to 3.5
1.0	0.77	2 to 4.5
1.5	0.716	4 to 6
2.0	0.695	4.5 to 8
2.5	0.667	5

Negative Voltage, Rod-Plane

0.5	0.88	2.5 to 4
1.0	0.76	5 to 9
1.5	0.726	4 to 5
2.0	0.665	4 to 7
2.5	0.592	10 to 14
3.0	0.623	17
3.5	0.614	9

Negative Voltage, Rod-Rod

0.5	0.57	3 to 14
1.0	0.55	5 to 19
1.5	0.52	7 to 18
2.0	0.51	12 to 23
2.5	0.50	12 to 34
3.0	0.56	13 to 20

Positive Voltage, Rod-Plane

0.5	0.386	8 to 18
1.0	0.375	15 to 25
1.5	0.390	17 to 20
2.0	0.407	6 to 16

Positive Voltage, Rod-Rod

0.5	0.48	4 to 10
1.0	0.458	9 to 19
1.5	0.46	9 to 16
2.0	0.445	15 to 16

Negative Voltage, Rod-Plane with MUE

(Note: These data were taken in a uniform field)

1.0	0.73	3 to 4
2.0	0.69	4 to 5

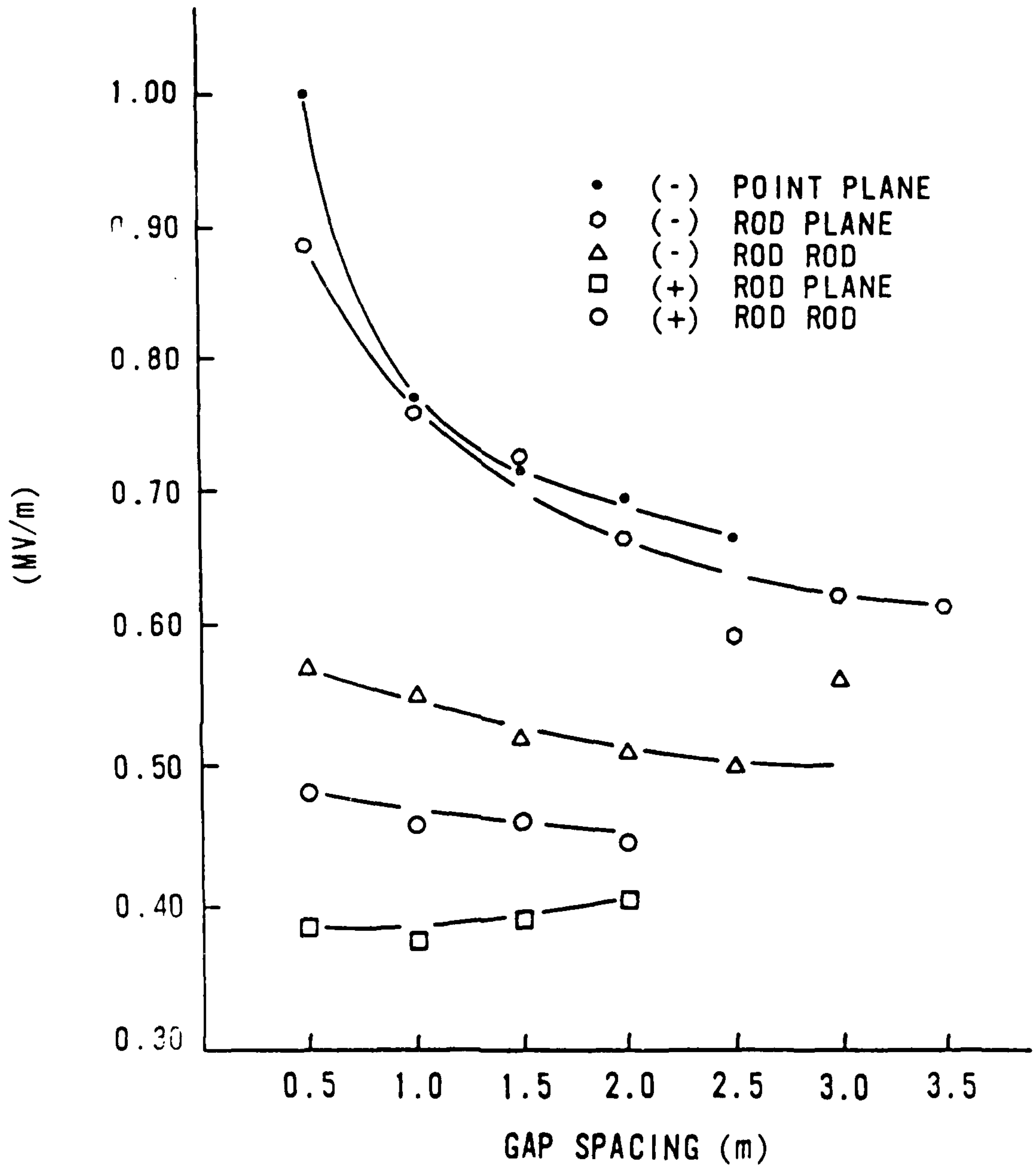


Figure 3. Hold-off versus spacing at 1 mi above sea level

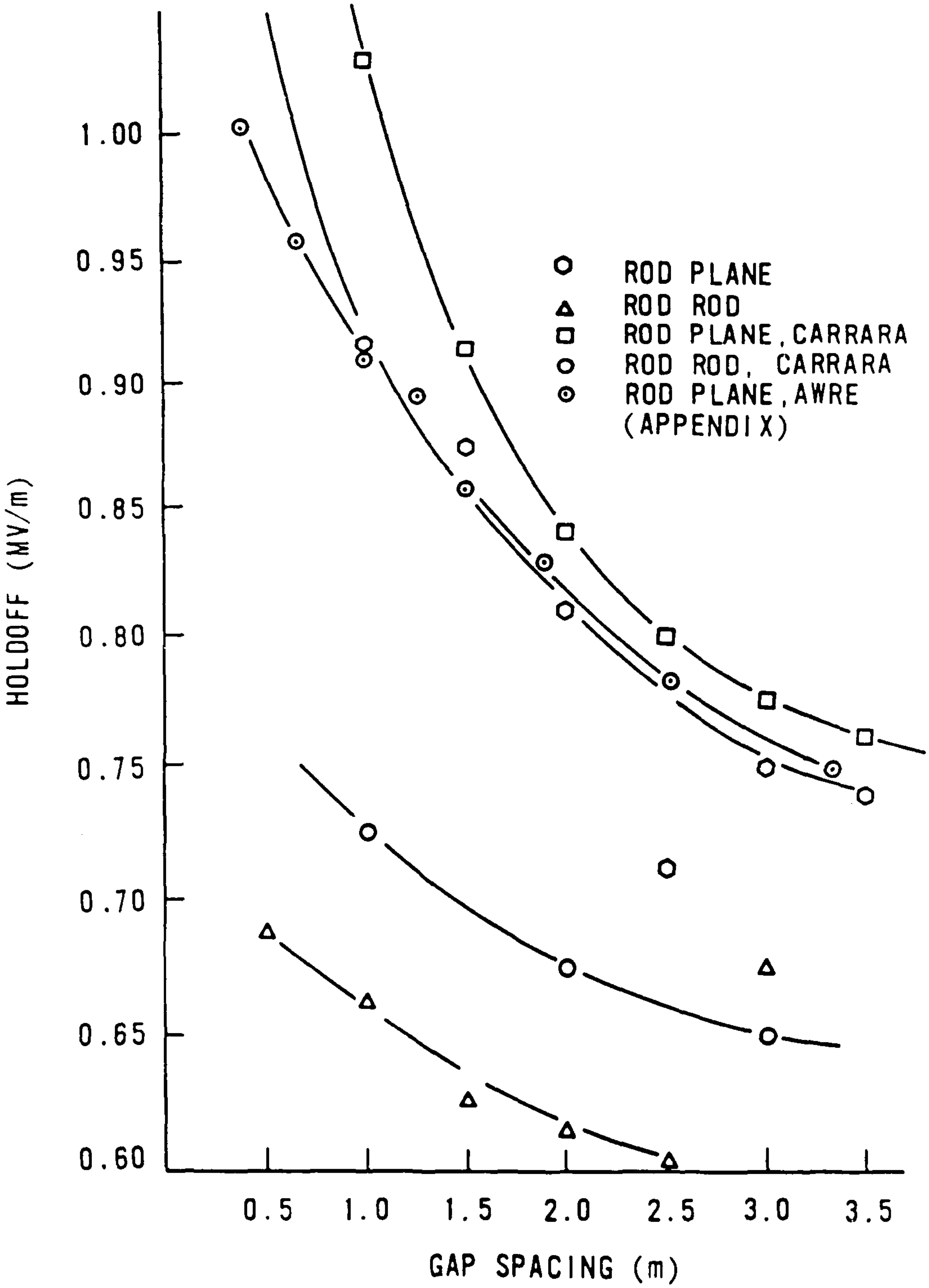


Figure 4. Comparison of negative FIG data (corrected to sea level) with AWRE data.

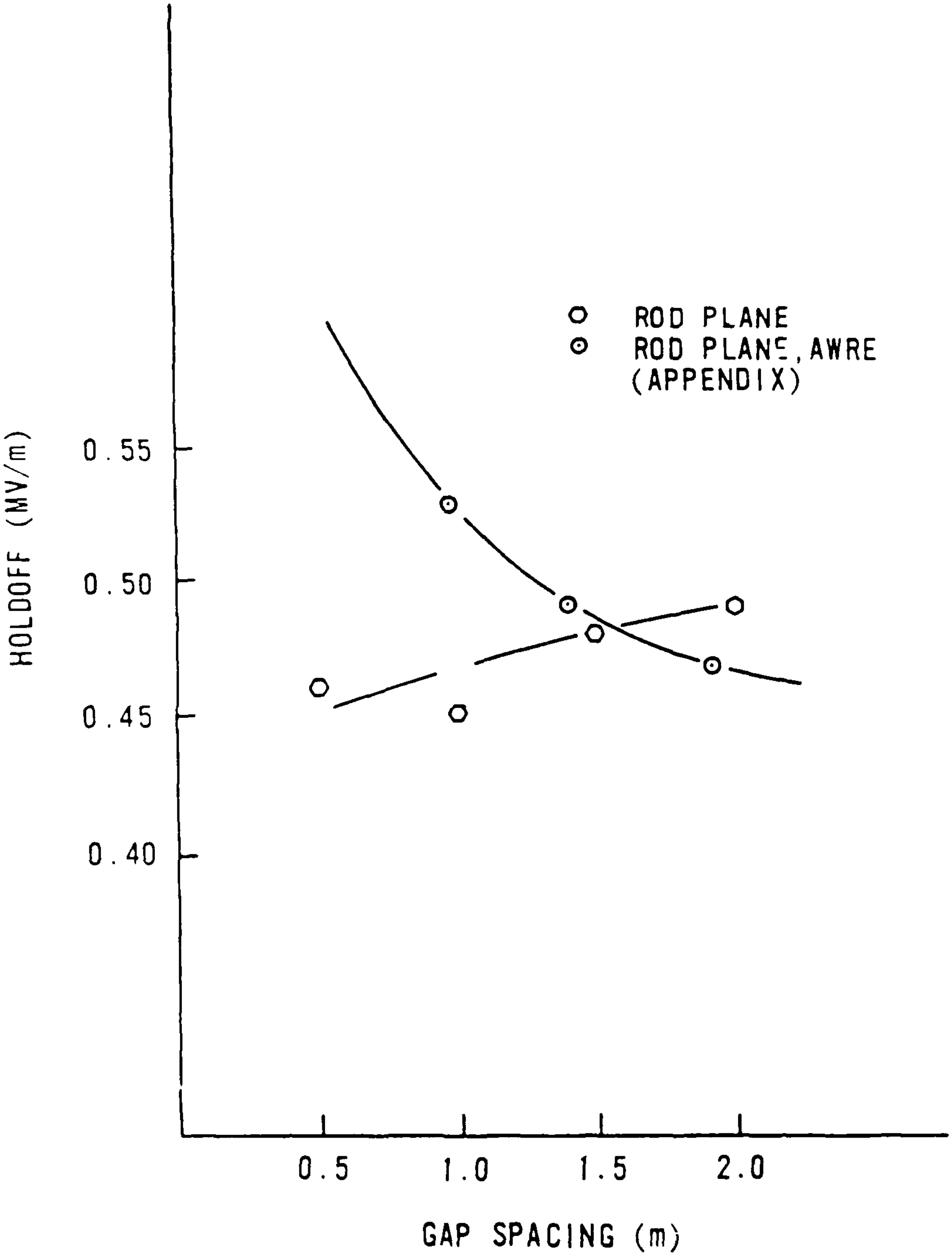


Figure 5. Comparison of positive FIG data (corrected to sea level) with AWRE data.

For a negative voltage worst case (rod-rod), a flashover will occur for a holdoff of 0.5 MV/m at large gap spacings (greater than 2 m) for a TWA waveform at 1 mi above sea level.

Variations in electrode geometry (rod-rod as compared to rod-plane) produce large variations in breakdown voltage, as can be seen in Fig. 3.

It appears from the data in Table 1 that the presence of a uniform field has little or no effect on the holdoff of a rod-plane geometry.

APPENDIX

CALCULATED STANDOFF VOLTAGES FOR ROD-PLANE GEOMETRIES

The following formulas (Eqs. A-1 and A-2) were developed by the British Atomic Weapons Research Establishment to calculate high voltage standoff distances for rod-plane gaps at sea level.

$$d(+) = \left(\frac{V\ t^{1/6}}{19.7}\right)^{6.5} \tag{A-1}$$

$$d(-) = \left(\frac{V}{19.7}\right)^{6.5} \tag{A-2}$$

Where d is the standoff distance in centimeters, V is the voltage in kilovolts, and t is the time in microseconds that the pulse is greater than 0.63 peak (28.5 μs for TWA).

The following values were calculated using the TWA waveshape.

Voltage (MV)	d(+) (m)	(+)Holdoff (MV/m)	d(-) (m)	(-)holdoff (MV/m)
0.5	0.947	0.528	0.485	1.031
0.7	1.418	0.494	0.725	0.966
0.9	1.917	0.469	0.981	0.917
1.1	2.439	0.451	1.248	0.881
1.3	1.981	0.436	1.525	0.852
1.5	3.539	0.428	1.811	0.828
2.0	4.998	0.400	2.558	0.782
2.5	6.533	0.383	3.343	0.748

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